Flood Frequency Analysis for the Congaree River at Columbia, South Carolina

Background

A flood frequency analysis was performed for the Congaree River at Columbia, South Carolina in support of Flood Insurance Studies in Richland and Lexington Counties, South Carolina. There is a gaging station on the Congaree River within the study reach. The gaging station Congaree River at Columbia (station 02169500, drainage area of 7,850 square miles) has systematic streamflow records from 1892 to 1998 with the gaging station operated by the National Weather Service (NWS) prior to 1939 and since then by the U.S. Geological Survey (USGS). Only peak stages were collected and published by NWS. A highwater stage-discharge relation was developed by the USGS in 1958.

The Congaree River is formed by the Saluda and Broad Rivers with the gaging station at Columbia just 1.4 miles downstream of the confluence of the two rivers. There is a gaging station on the Saluda River near Columbia (station 02169000, drainage area of 2,520 square miles) with systematic streamflow records from 1926 to 1998. There is also a gaging station on the Broad River at Richtex (station 02161500, drainage area of 4,850 square miles) with systematic streamflow records from 1926 to 1983.   Peak flows for the Saluda River near Columbia have been regulated by Lake Murray since 1930. Water in Lake Murray is used for hydropower generation and there is no dedicated flood storage.

Bulletin 17B guidelines (Interagency Advisory Committee on Water Data, 1982) were used to estimate flood discharges for the Congaree River even though there is some regulation in the watershed. The annual peak flows are regulated to some degree and the Pearson Type III distribution fits the logarithms of the regulated data reasonably well. Issues related to the flood frequency analysis are:

- the appropriate length of record or data base to use;
- the effect of Lake Murray on peak flows;
- the utility or applicability of historical peak flows;
- use of weighted or station skew; and,
- appropriate record extension techniques.

Another issue that complicates the frequency analysis is time-sampling error as more major floods occurred prior to 1930 than after this date. The paucity of major floods since 1930 makes it more difficult to estimate the effect of regulation from Lake Murray using observed data.

Flood frequency analyses were performed for the Congaree River using various analysis approaches and data sets to define the 1-percent annual chance (base) flood discharge for floodplain mapping. The following is a general description of four of these approaches along with a less rigorous independent quantitative check whose purpose is to provide an added level of comfort regarding the results obtained using the four approaches outlined here.

Flood Frequency Analyses – Approaches 1 through 4

Approach 1 – August 12, 1999 Revised Preliminary

The base (1-percent annual chance) flood discharges for the Revised Preliminary Flood Insurance Studies dated August 12, 1999 for Lexington and Richland Counties were estimated using data at gaging station 02169500 for the period 1926 to 1996. Regulated observed peak flows from 1931 to 1996 were used. The unregulated flows from 1926 to 1930 were converted to regulated conditions using peak flows for the Broad River at Richtex. A linear regression equation was developed between regulated peak flows for the Congaree and unregulated peak flows for the Broad River using concurrent peak flows for the period 1930 to 1983. Regulated peak flows for the Congaree River for 1926 to 1930 were estimated using the following regression equation and unregulated peak flows for the Broad River:

$$Q_{1695} = 0.5934 * (Q_{1615})^{1.0622} \qquad\qquad (1)$$

where Q_{1695} is the estimated regulated peak flow in cubic feet per second (cfs) for the Congaree River and Q_{1615} is the unregulated peak flow in cfs for the Broad River.

The base flood discharge computed from this analysis and used for the August 1999 Revised Preliminary is 253,000 cfs based on weighting the station and regional skew from Plate I of Bulletin 17B.

Summary of Approach 1
Data Set – 1926 to 1996
Adjustments –
  Used observed data from 1931 to 1983 and linear regression to develop a relation between unregulated Broad River peak flows and regulated Congaree River peak flows.
  Converted observed unregulated Congaree River peak flows from 1926 to 1930 to regulated peak flows using the regression relation with Broad River.
Skew – Weighted the station and regional skews because Congaree River assumed to be essentially unregulated.
Strengths – Uses only highly correlated data between the Congaree and Broad Rivers to estimate regulated peak flows for the Congaree River.
Weaknesses – Does not use entire dataset for the Congaree River because data prior to 1926 for the Broad River at Richtex are not available. Several large floods occurred prior to 1926.
Result – Base flood discharge = 253,000 cfs.

Approach 2 - Maintenance of Variance Extension (MOVE) – estimated regulated peak flows for 1926 to 1929

Hirsch (1982) has shown there is a loss of variance associated with data estimated by linear regression. He proposed methods called Maintenance of Variance Extension (MOVE) that

maintain the variance of the estimated data. In other words, the variance of the estimated data is equivalent to the observed data at the given site. For linear regression techniques, the low peak flows are estimated too high and the high peak flows too low (hence the loss of variance). The MOVE techniques estimate the slope of the linear relation using a ratio of the standard deviations of the dependent and independent variables in contrast to linear regression where this ratio is estimated by the correlation coefficient times this ratio. Since the correlation coefficient is always equal to or less than 1, this implies that the slope of the MOVE relation will be steeper than that using linear regression.

In the context of flood frequency analysis, the objective of the MOVE techniques is to use data at a long-term gaging station to estimate or extend data for a short-term station. Hirsch (1982) describes two MOVE techniques, MOVE.1 and MOVE.2. For MOVE.1, the linear relation is defined by using data for the concurrent period, the length of record for the short-term station. The MOVE.1 relation is defined as follows:

$$Y = \overline{Y}_1 + \frac{Sy_1}{Sx_1}[X - \overline{X}_1]$$

(2)

where Y is the estimated peak flows for the short-record station, X is the peak flow not observed at the short-record station, Y_1 and X_1 are the means for the concurrent period (N_1 years), and Sy_1 and Sx_1 are the standard deviations of Y and X for the concurrent N_1 data points. Equation 2 differs from a linear regression equation in terms of the slope. For linear regression, the slope of the equation is $r * (Sy_1/Sx_1)$, where r is the correlation coefficient. Typically, the MOVE analysis utilizes the logarithms of the data because the logarithmic relation tends to be more linear. The MOVE equation can then be converted to exponential form similar to Equation 1.

In MOVE.2, additional data are used estimating the means and standard deviations in Equation 2. The mean and standard deviation of Y are estimated using the Two-Station Comparison method described in Appendix 7 of Bulletin 17B. The mean and standard deviation of X are estimated using all the data for the long-term station, i.e., the N_1 concurrent years plus the N_2 years of record not available at the short-term station. Hirsch (1982) demonstrated that the MOVE.2 technique is slightly superior to MOVE.1.

The MOVE.2 technique is described in Appendix 1 and used to estimate regulated peak flows for the Congaree River for 1926 to 1929 using unregulated peak flows for the Broad River at Richtex. Peak flow for the 1930 water year (October 1929) for the Congaree River was considered regulated (Lake Murray was filling) and was used in defining the following MOVE.2 relation:

$$Q_{1695} = 0.3533 * Q_{1615}^{1.109}$$

(3)

where Q_{1695} is the regulated peak flow in cfs for the Congaree River and Q_{1615} is the unregulated peak flow for the Broad River at Richtex. Data for 51 **concurrent** years during the period 1930 to 1983 were used in the analysis. The correlation coefficient between the 51 concurrent peak flows was 0.96. Equation 3 was derived using the **linear logarithmic** form shown in Appendix

1. The linear logarithmic form of the equation was converted to the exponential form as shown in Equation 3 for ease of use.

The base flood discharge for this analysis was 275,000 cfs using station skew rather than a weighted skew. The frequency curve is shown in Figure 1 and the output from the USGS PEAKFQ program is given in Appendix 2. The standard error of the base flood discharge is 0.092466 log units (+23.7 percent, -19.2 percent) based on 73 years of record (Kite, 1988). This conforms to a 68 percent confidence interval of 222,000 to 340,000 cfs for the base flood estimate of 275,000 cfs.
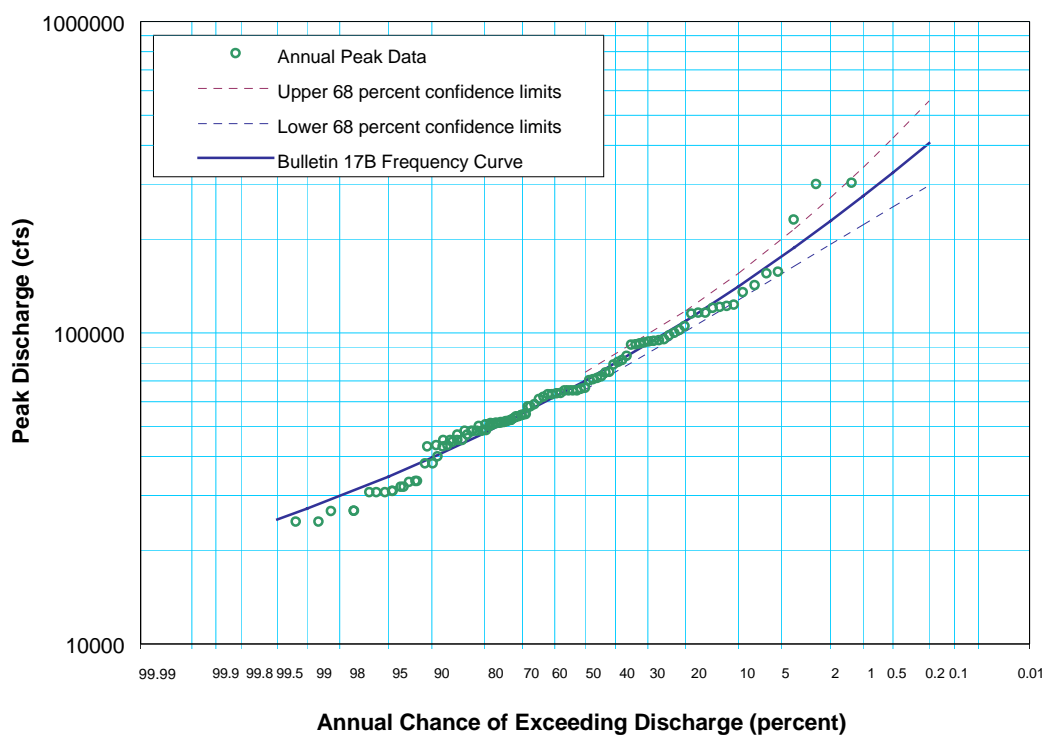
Figure 1. Flood frequency curve for the Congaree River using data from 1926 to 1998. Data for 1926 to 1929 estimated using MOVE.2.

The regional skew map in Bulletin 17B was developed using data for watersheds less than 3,000 square miles and for **essentially unregulated** peak flow records. Essentially unregulated was defined as periods when the annual peak discharge differed by less than 15 percent from natural flow. Since the Congaree River has a drainage area of 7,850 square miles and the lower peak

flows differ by more than 15 percent from natural conditions (discussed later), the station skew was not weighted with the regional skew.

The Congaree River and the Broad River were not used in developing the regional skew map in Bulletin 17B or the regional regression equations for South Carolina because these watersheds encompass more than one homogeneous region. For example, the Congaree River originates in the Blue Ridge Province of North Carolina and flows eastward and southward through the Piedmont Province to the Upper Coastal Plain in South Carolina. The skew varies from about +0.1 in the headwaters of the Congaree River to about –0.1 at station 02169500. The skew value at the gaging station is not indicative of skew for the entire watershed.

It is common practice in hydrology to use a regional technique (such as regional regression equations) only within the range of the calibration data. This concept is also applicable to the regional skew map in Bulletin 17B. Furthermore, the Bulletin 17B skew map does not appear to reflect the effects of hurricane floods that have occurred in South Carolina. Station skew was computed as 0.282 for 94 years of record for the Saluda River at Chappells and 0.636 for 58 years of record for the Broad River at Richtex whereas the Bulletin 17B skew map shows negative skew values at these gaging stations.

Summary of Approach 2
Data Set – 1926 to 1998
Adjustments –
> *Used observed data from 1930 to 1983 and MOVE.2 to develop a relation between unregulated Braod River peak flows and regulated Congaree River peak flows.*
> *Converted observed unregulated Congaree River peak flows from 1926 to 1930 to regulated flows using relationship based on MOVE.2 relation with Broad River.*

Skew – Unweighted station skew used because the drainage area of the Congaree River is greater than 3,000 square miles and the lower peak flows differ by more than 15 percent from natural conditions.
Strengths – Uses established technique for extending the record for the Congaree River prior to construction of the dam. Uses only highly correlated data to make those adjustments (data for the Broad and Congaree Rivers).
Weaknesses – Does not use entire dataset for Congaree because adjustments prior to 1926 cannot be well established (no Broad River data). Several large floods occurred prior to 1926.
Result – Base flood discharge = 275,000 cfs.

Method 3 - Maintenance of Variance Extension (MOVE) – estimated regulated peak flows for 1892 to 1929

Many years of unregulated peak flows are available for the Congaree River prior to 1930 when Lake Murray was completed. An approach for adjusting the unregulated peak flows for the period 1892 to 1925 was developed using the MOVE.2 relation of Equation 3 and the unregulated peak flows for 1927 and 1928. The latter two years are the only **concurrent** peak flows between the Congaree and Broad Rivers for the unregulated period 1926 to 1929.

Fortunately, the peak flow in 1927 was the second lowest unregulated peak flow and 1928 was second highest in the period 1892 to 1929. These two peak flows define the unregulated relation between Congaree and Broad Rivers. The unregulated relation shown in Figure 2 provides estimates of peak flows for the Congaree River almost the same as using the drainage area ratio $(A_{1695}/A_{1615})^{0.69} * Q_{1615}$, where A_{1695} and A_{1615} are the drainage areas in square miles for the Congaree and Broad Rivers, respectively. The exponent 0.69 is from the 1-percent chance regression equation for the Upper Coastal Plain (Guimaraes and Bohman, 1991). The MOVE.2 relation of Equation 3 defines the regulated-unregulated relation. The two relations are shown in Figure 2. The data for 1926, 1929 and 1936 were not used in defining the unregulated relation in Figure 2 but are shown to verify the applicability of the relation.

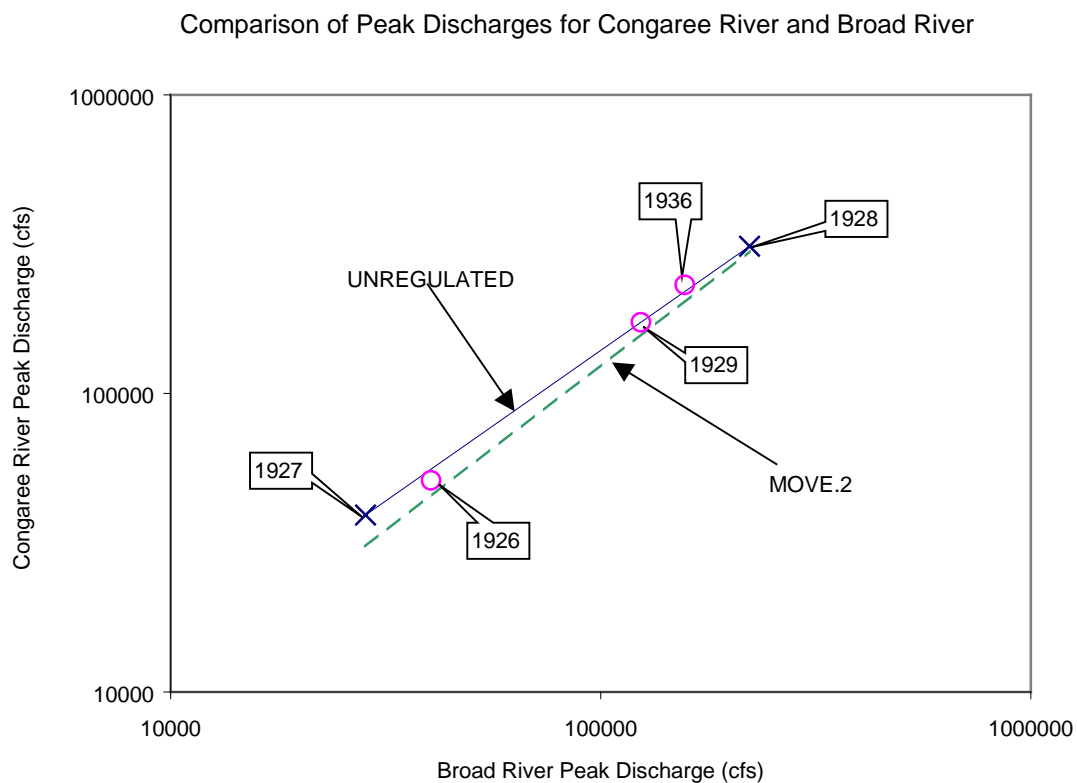Comparison of Peak Discharges for Congaree River and Broad River

Figure 2. Unregulated and MOVE.2 relation between the Congaree and Broad Rivers.

Using the observed and MOVE.2 estimated peak flows for 1927 and 1928, the following equation was developed for estimating regulated peak flows for the Congaree River as a function of the unregulated peak flows at the Congaree River for the period 1892 to 1925:

$$Q_{1695} \text{ (reg)} = 0.2747 * [Q_{1695} \text{ (unreg)}]^{1.0993} \tag{4}$$

where Q_{1695} (reg) is the regulated peak flow in cfs for the Congaree River and Q_{1695} (unreg) is the unregulated peak flow. Equation 4 was defined using: 1927 flows of 39,100 cfs unregulated and 30,700 cfs regulated (MOVE.2 estimate); 1928 flows of 311,000 cfs unregulated and 300,000 cfs regulated (MOVE.2 estimate). Using unregulated peak flows for 1892 to 1925 and Equation 4, regulated peak flows were estimated. The reduction in peak flows ranged from 23 percent for the lowest annual peak of 34,500 cfs in 1907 to 2 percent for the highest peak flow of 364,000 cfs in 1908.

A Bulletin 17B analysis was then performed on estimated regulated flows from Equation 4 for the period 1892 to 1925, MOVE.2 estimated flows from Equation 3 for 1926 to 1929 and observed regulated peak flows from 1930 to 1998. The 1908, 1928 and 1930 floods were assumed to be the highest since 1852 and a historical adjustment was applied to these peak flows. The historical peak flows are summarized in Table 1 below. The historical peak flows (before 1892) were not used in the frequency analysis but were used to determine the high-outlier threshold and historic period.

A high-outlier threshold of 299,000 cfs was used with a historical period of 146 years (1852 to 1998). The threshold value was chosen to be slightly less than the 1930 flood, the lowest peak flow for which the historical adjustment was applied. The base flood discharge from this analysis was 292,000 cfs based on station skew. The reasoning for using station skew is as described above. The frequency curve is shown in Figure 3 and the output from the USGS PEAKFQ Program is given in Appendix 3. The standard error of the base flood discharge is 0.07439 log units (+18.7 percent, -15.7 percent) based on 107 years of record. This conforms to a 68 percent confidence limit of 246,000 to 347,000 cfs for the base flood estimate of 292,000 cfs.

The sensitivity of the historical adjustment was evaluated by rerunning the analysis and only applying the historical adjustment to the 1908 flood. This analysis resulted in a base flood discharge of 304,000 cfs using station skew. Based on data provided in Table 1, it is clear that the 1908 flood is the highest since at least 1840. However, it is less likely that the 1928 and 1930 floods are the highest since 1852. Therefore, the most logical approach may be to apply the historical adjustment only to the 1908 flood.
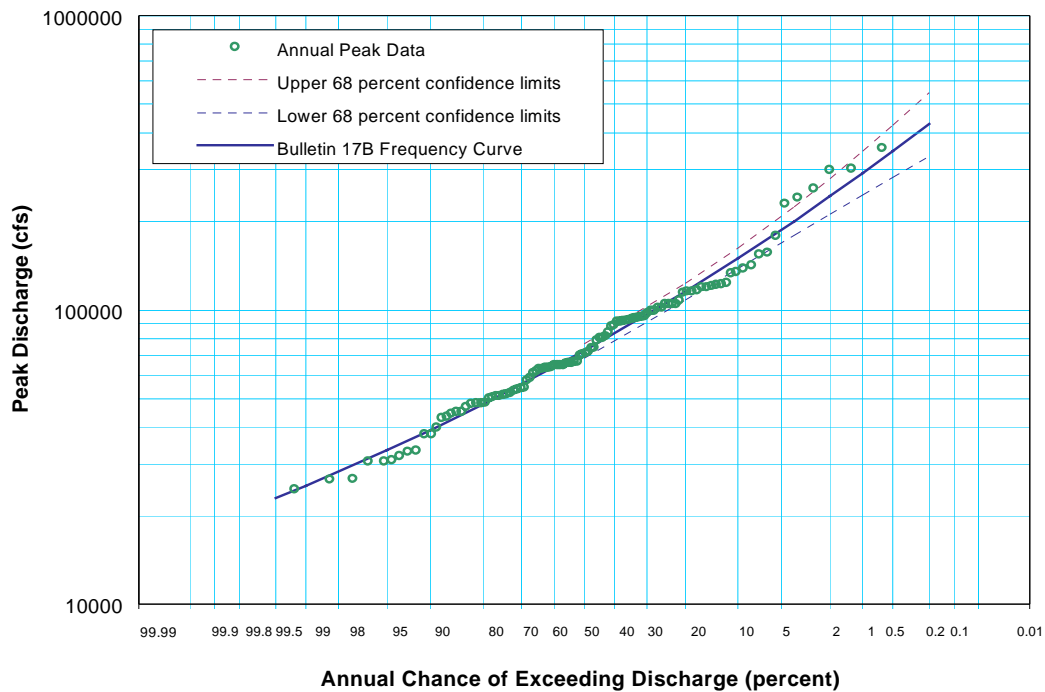
Figure 3. Flood frequency curve for the Congaree River using data from 1892 to 1998. Data for 1892 to 1929 estimated using MOVE.2 with 1908, 1928 and 1930 adjusted for historical information.

Historical peak flows are recorded in The State newspaper, and records of the National Weather Service and USGS. Historical peak flows and the largest peak flows during systematic streamgaging are shown in Table 1. The historical peak flows for the period 1840 to 1888 were estimated using USGS Rating No. 6 with the assumption that this rating was applicable to channel conditions in the 1800's. Of the historical floods between 1840 and 1888, only the peak stage for the 1852 flood is published by USGS and available in their data base.

Table 1. Summary of major floods for the Congaree River at Columbia, South Carolina. (Historical peak flows were estimated using USGS Rating No. 6.)

Date of flood	Stage (feet)	Peak flow (cfs)
August 1840	33.7	314,000
August/September 1852	34.4	330,000
February 1865	34.0	320,000
May 1885	31.3	256,000
June 1886	30.3	234,000
September 1888	33.3	304,000
August 1908	35.8	364,000
March 1912	30.7	256,000
July 1916	31.5	272,000
August 1928	33.5	311,000
October 1929	33.1	303,000

Summary of Approach 3
Data Set – 1892 to 1998
Adjustments –
> *Used observed data from 1927and 1928 floods and MOVE.2 relation to determine the effect of the dam on Congaree River peak flows for floods of various sizes.*
> *Converted observed unregulated Congaree River peak flows from 1892 to 1925 to regulated flows using relationship based on 1927 and 1928 floods.*

Skew – Unweighted station skew used because the drainage area of the Congaree is greater than 3,000 square miles and the lower peak flows differ by more than 15 percent from natural conditions.
Strengths – Uses all observed data for the Congaree River. The unregulated relation is relatively well supported by three other floods (1926, 1929, 1936).
Weaknesses – Uses only two data points to determine the effect of Lake Murray on the Congaree River unregulated peak flows.
Result – Base flood discharge = 292,000 cfs or 304,000 cfs by applying a historical adjustment to three peak flows or one peak flow, respectively.

<u>Approach 4 - Record extension using the Tar River at Tarboro, North Carolina</u>

An alternative approach to that illustrated in Figure 2 for estimating regulated peak flows for the Congaree River would be to use data from a long-term gaging station with **unregulated** data for the period 1892 to 1929. Although there are no such gaging stations in South Carolina, there are gaging stations in neighboring states with sufficiently long records. A search of USGS records indicated the following: French Broad River at Asheville, North Carolina (03451500) has record from 1896 to 1998; Oostanaula River at Resaca, Georgia (02387500) has record from 1892 to 1998; and Tar River at Tarboro, North Carolina (02083500) has record from 1897 to 1998 with a few missing years in the early 1900's. Of these stations, only the Tar River has sufficiently high correlation with the Congaree River to warrant extending the regulated record.

The Tar River (drainage area of 2,183 square miles) has systematic streamflow records from 1897 to 1900 and 1906 to 1998. During the period 1930 to 1998, there are 30 **concurrent** peak flows with the Congaree River. The correlation coefficient for these concurrent data is 0.455. Although this correlation coefficient is not very high, it is high enough to insure that the extended record will have improved estimates of the mean and standard deviation. (See page 7-9 in Appendix 7 of Bulletin 17B which indicates the correlation must only exceed 0.39 for 30 years of concurrent record.)

The following MOVE.2 relation was developed using the 30 years of concurrent data:

$$Q_{1695} = 1.1034 * (Q_{0835})^{1.16306} \qquad (6)$$

where Q_{0835} are the peak flows in cfs for the Tar River. Equation 6 was used to estimate regulated peak flows for the Congaree River for 1897 to 1900 and 1906 to 1929. A Bulletin 17B analysis was performed on the estimated flows from Equation 6 and the observed regulated flows from 1930 to 1998. The base flood discharge from this analysis is 285,000 cfs based on station skew. The input data for the MOVE.2 analysis is given in Appendix 1, and the output from the USGS PEAKFQ Program is given in Appendix 4.

Summary of Approach 4
Data Set – 1897 to 1998
Adjustments –
> *Used observed data from 1930 to 1998 and MOVE.2 to determine a relation between unregulated Tar River peak flows and regulated Congaree River peak flows.*
> *Converted observed Tar River peak flows from 1897 to 1900 and 1906 to 1929 to regulated Congaree River peak flows using relation based on Tar River data.*

Skew – Unweighted station skew used because the drainage area of the Congaree is greater than 3,000 square miles and the lower peak flows differ by more than 15 percent from natural conditions.
Strengths – Uses data back to 1897.
Weaknesses – Relatively low (but acceptable) correlation between Congaree and Tar River data (0.455)
Result – Base flood discharge = 285,000 cfs.

Summary and Discussion

Flood frequency analyses were performed using four analysis approaches and data sets to evaluate the sensitivity of base flood estimates. Base flood discharges for all four analyses discussed above are shown in Table 2. Flood frequency analyses using weighted and station skew are shown to illustrate the sensitivity of skew on the base flood estimate.

Table 2. Summary of base flood discharges for the Congaree River using different data sets.

Analysis Approach	Base Flood Discharge (cfs) (Weighted skew)	Base Flood Discharge (cfs) (Station skew)
1. August 1999 Analysis Regression for 1926-30 Observed data 1931-96	253,000 (0.299)	265,000 (0.430)
2. MOVE.2 for 1926-29 Observed data 1930-98	262,000 (0.328)	275,000 (0.471)
3a. MOVE.2 for 1926-29 **Adjusted** data for 1892-1925 Observed data 1930-98 Hist. adj. 1908, 1928, 1930	285,000 (0.289)	292,000 (0.355)
3b. MOVE.2 for 1926-29 **Adjusted** data for 1892-1925 Observed data 1930-98 Hist. adj. for 1908 flood	296,000 (0.317)	304,000 (0.390)
4. Tar River extension MOVE.2 1897-1929 Observed data 1930-98	269,000 (0.471)	285,000 (0.643)

The data in Table 2 indicate a range of base flood discharges from 253,000 to 304,000 cfs.

Approach 1 with weighted skew uses linear regression to estimate the regulated record for 1926-30. While technically accurate, this approach for record extension may be less appropriate than MOVE.2 (Hirsch, 1982). The use of weighted skew is considered less appropriate than the station skew for the Congaree River due to the size of the watershed (greater than 3,000 square miles) and the regulated nature of peak flows.

Approach 2 estimates the extended record (1926-29) using MOVE.2 and the unregulated peak flows for the Broad River at Richtex. The correlation coefficient between the concurrent Congaree and Broad River peak flows is 0.960. This provides confidence that the estimated peak flows are reasonable from a statistical perspective. Also the use of station skew is considered more appropriate for the Congaree River analysis because of the size of the watershed and the regulated nature of the peak flows. One weakness with this approach is that it does not use the entire period of record (1892 to 1998).

Approach 3 uses data from 1892 to 1998 including the adjusted systematic data prior to construction of Lake Murray. This makes this approach very attractive but the weakness of this approach is that the method for adjusting the peak flows from 1892 to 1925 (illustrated in Figure 2) may underestimate the effect of Lake Murray. In other words, the adjusted peak flows may be too high. Approaches 3a and 3b differ only in the number of major floods for which the historical adjustment was applied. For Approach 3a, the historical adjustment was applied to the 1908, 1928 and 1930 floods. For Approach 3b, the historical adjustment was only applied to the

1908 flood. The latter approach may be slightly superior because it is more certain that the 1908 flood is higher than any flood that occurred in the 1840 to 1892 period.

Approach 4 is attractive because the regulated peak flows for the Congaree River are extended back to 1897. The weakness of this approach is that the correlation between the Congaree River and Tar River is only 0.455. While this is sufficiently high to get improved estimates over using the shorter record, the low correlation coefficient lessens our confidence in the results.

Independent Quantitative Checks

One of the major issues in the flood frequency analysis for the Congaree River is the degree of regulation afforded by Lake Murray. Theoretically, the upper and lower bounds of the base flood discharge along the Congaree River would vary with the degree of regulation. The lower bound being the condition for which Lake Murray prevents upstream floodwater from entering the Congaree River and the upper bound being that when Lake Murray does not attenuate any of the floodwater entering the Congaree River.

One way to estimate of the upper bound base flood discharge for the Congaree River would be to use the observed peak flows from 1892 to 1998 as given in the USGS data base. Peak flows from 1892 to 1929 are unregulated and those from 1930 to 1998 have some unknown degree of regulation. Using 107 years of record, station skew and adjusting the 1908 flood for historical information results in a base flood discharge of 319,000 cfs. If the historical peak flows for the period 1840 to 1888 were used (Table 1), the estimate of the base flood discharge would be higher than 319,000 cfs.

An estimate of the lower bound for the base flood discharge could be obtained by assuming a high degree of regulation for Lake Murray. Alternative independent analyses using gaging station data upstream and downstream of the dam and other information indicates that Saluda River base flood discharge could be reduced by as much as 50 percent by Lake Murray. Since the Saluda River represents 30 percent of the Congaree River watershed, the degree of regulation of the base flood discharge for the Congaree River can be estimated as approximately15 percent.

In Approach 3 described above (Figure 2), the degree of regulation for the base flood estimate for the Congaree River was estimated as approximately 5 percent. Since the degree of regulation could be as high as 15 percent, the MOVE.2 relation in Figure 2 was lowered 10 percent while maintaining the same slope. This amounts to reducing the constant in Equation 4 from 0.2747 to 0.2472. The modified equation was used to estimate peak flows from 1892 to 1929 and a Bulletin 17B analysis performed. The annual peak flows were reduced from 33 to 12 percent depending on flow magnitude.

The base flood discharge was 269,000 cfs when applying a historical adjustment to the 1908, 1928 and 1930 floods (corresponds to 292,000 cfs in Approach 3a in Table 2) and 280,000 cfs when only the 1908 flood was adjusted for historical information (corresponds to 304,000 cfs for Approach 3b in Table 2).

Therefore, the base flood estimates ranged from 269,000 to 319,000 cfs for this independent check for reasonableness of the values given in Table 2.

Finally, an analysis of the peak flows for the Broad River at Richtex (station 02161500) was performed. The Broad River portion of the Congaree River watershed is unregulated and this subwatershed accounts for 4,850 square miles at gaging station 02161500 and 5,340 square miles at the mouth. Observed record exists for station 02161500 for the period 1926 to 1983. The USGS published a base flood estimate of 225,000 cfs using the observed period of record (Guimaraes and Bohman, 1991). Using the MOVE technique, the peak flows from 1984 to 1998 were estimated using regulated flows for the Congaree River. Using a drainage area ratio to the 0.69 power, peak flows were estimated for the period 1892 to 1925 using unregulated peak flows from the Congaree River (this is essentially the unregulated relation in Figure 2).

A Bulletin 17B analysis was performed on the estimated (1892 to 1925 and 1984 to 1998) and observed data (1926 to 1983), a total of 107 years. The base flood discharge at the Richtex gage was computed as 226,000 cfs using station skew and 220,000 cfs using weighted skew with the 1908 flood adjusted for historical information in both cases. Transposing the 226,000 cfs downstream to the mouth of the river using a drainage-area ratio gives a base flood estimate of 242,000 cfs for the 5,340-square-mile watershed (70 percent of the Congaree River watershed).

These less technical, but quantitative, computations give further credence to the discharges presented in Table 2. Although there are inherent technical weakness in Approaches 3 and 4, the above quantitative analyses tend to suggest that they may be more appropriate than base flood estimates from Approaches 1 and 2.

References

Guimaraes, W. B. and Bohman, L. R., 1991, *Techniques for Estimating Magnitude and Frequency of Floods in South Carolina, 1988*: U.S. Geological Survey Water-Resources Investigations Report 91-4157, 174 p.

Hirsch, R. M., 1982, *A Comparison of Four Streamflow Record Extension Techniques*: Water Resources Research, Vol. 18, No. 4, pages 1081-1088.

Interagency Advisory Committee on Water Data, 1982, *Guidelines for Determining Flood Flow Frequency*: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Virginia, 183 p.

Kite, G. W., 1988, *Frequency and Risk Analyses*: Water Resources Publications, Littleton, Colorado, 257 p.

Appendix 1. A description of MOVE.2 and its application to estimating peak flows for the Congaree River.

A MOVE.2 relation was developed using 51 years of concurrent peak discharge data during the period 1930-83. Regulated flows were used for the Congaree River at Columbia, SC (02169500) and unregulated flows for the Broad River at Richtex, SC (02161500). The objective is to estimate regulated peak discharges for the Congaree River for the period 1926 to 1929 using unregulated data for the Broad River and the MOVE.2 relation.

The MOVE.2 equation is:

$$Y_{1695} = \overline{Y} + \frac{Sy}{Sx}\left[X_{1615} - \overline{X}\right]$$

where

Y_{1695} = regulated peak discharges for the Congaree River, in log units,

X_{1615} = unregulated peak discharges for the Broad River, in log units,

$\overline{X}$ = mean logarithm for Broad River, 1926-83,

S_x = standard deviation of logarithms for Broad River, 1926-83,

$$\overline{Y} = \overline{Y}_1 + \frac{N_2}{N_1 + N_2}\left[b\left(\overline{X}_2 - \overline{X}_1\right)\right]$$

(Equation 7-5a for Two-Station Comparison in Appendix 7 of Bulletin 17B)

$$b = r\frac{S_{y1}}{S_{x1}}, r = \text{ correlation coefficient}$$

N_1 = concurrent period of record (51 years)

N_2 = additional years available at Broad River (4 years, 1926-29)

$\overline{X}_1$ = mean logarithm for Broad River for N_1 years

$\overline{X}_2$ = mean logarithm for Broad River for N_2 years

S_{y1} = standard deviation of logarithms for Congaree River for N_1 years

S_{x1} = standard deviation of logarithms for Broad River for N_1 years

and

$$S_y{}^2 = \frac{1}{(N_1 + N_2 - 1)}\left[(N_1 - 1)S_{y1}{}^2 + (N_2 - 1)\ b^2 S_{x2}{}^2 + \frac{N_2(N_1 - 4)(N_1 - 1)}{(N_1 - 3)(N_1 - 2)}\ (1 - r^2)S_{y1}{}^2 + \frac{N_1 N_2}{N_1 + N_2}\ b^2(\overline{X}_2 - \overline{X}_1)^2\ \right]$$

(Equation 7-10 for Two-Station Comparison in Appendix 7 of Bulletin 17B)

Appendix 1. continued -- Data used in defining the MOVE.2 relation (Equation 3) between the Congaree and Broad Rivers (peak flows in cfs).

	Water Year	Congaree River	Broad River
1	1930	228000	303000
2	1931	23000	26800
3	1932	51200	71600
4	1933	101000	115000
5	1934	34400	33400
6	1935	84600	92300
7	1936	157000	231000
8	1937	72400	70900
9	1938	55800	57900
10	1939	53400	66400
11	1940	120000	121000
12	1941	49400	52000
13	1942	53300	52400
14	1943	57200	63400
15	1944	84700	105000
16	1945	96600	102000
17	1946	59200	62200
18	1947	57800	63400
19	1948	49400	54400
20	1949	95700	116000
21	1950	52000	50200
22	1951	30600	32000
23	1952	84700	91400
24	1953	42000	43500
25	1954	64700	65200
26	1955	43200	47000
27	1956	42000	43100
28	1957	31800	31000
29	1958	55200	64000
30	1960	55900	65200
31	1961	56600	74400
32	1962	55900	65200
33	1963	75300	91800
34	1964	99500	142000
35	1965	102000	120000
36	1966	65300	80600
37	1967	74500	97900
38	1968	46200	61200
39	1969	52700	94200
40	1970	40600	45200
41	1971	58000	79100
42	1972	45800	63900
43	1973	73700	99800
44	1975	94900	122000
45	1977	146000	155000
46	1978	64500	81700
47	1979	72300	94500
48	1980	64200	93100
49	1981	46700	51300
50	1982	62100	84200
51	1983	48400	66000

Appendix 1. continued -- Input data for the MOVE.2 method for estimating regulated peak flows for the Congaree River (Y variable) for 1926-29 based on peak flows at Broad River (X variable):

N_1 = 51 years
N_2 = 4 years
$\overline{X}_1$ = 4.798871 log units
$\overline{X}_2$ = 4.874681 log units
S_{y1} = 0.205378 log units

$\overline{Y}_1$ = 4.87022 log units
S_{x1} = 0.183880 log units
r = 0.96 (correlation coefficient)

This values are substituted in Equation 7-5a of Bulletin 17B to get an improved estimate of the mean,

$\overline{Y}$ = 4.876134 log units
S_{x2} = 0.4165631 log units (standard deviation of logarithms of Broad River peak flows for 1926-29)

The above values are substituted in Equation 7-10 of Bulletin 17B to get improved estimates of the standard deviation, Sy = 0.22549 log units.

$\overline{X}$ = 4.804384 log units
S_x = 0.203328 log units

The above values are substituted in the following equation to get the MOVE.2 relation

$$Y_{1695} = \overline{Y} + \frac{Sy}{Sx}\left[X_{1615} - \overline{X}\right]$$

Y_{1695} = 4.876134 + 0.22549/0.203328 * $[X_{1615} - 4.804384]$
Taking the antilog of the above equation yields Equation 3 given earlier in the text:

$$Q_{1695} = 0.3533 * Q_{1615}^{1.109}$$

Water year	Broad River observed (Q_{1615})	MOVE.2 estimated (Q_{1695})
1926	40,300	45,200
1927	28,400	30,700
1928	222,000	300,000
1929	124,000+	157,000

+ estimated as $(A_{1615}/A_{1695})^{0.69}$ * Q_{1695}, since station not in operation during annual maximum flood

Appendix 1. continued -- Input data for the MOVE.2 method for estimating regulated peak flows for the Congaree River for 1897 to 1900 and 1906 to 1929 based on peak flows at Tar River:

Input data for MOVE.2 analysis (Equation 6 analysis)

Water year	Tar River (cfs)	Congaree River (cfs)
1930	24000	303000
1934	15900	33400
1936	20200	231000
1940	37200	121000
1941	8460	52000
1943	10800	63400
1944	13800	105000
1945	24600	102000
1947	6570	63400
1948	19800	54400
1949	15300	116000
1952	17600	91400
1953	9950	43500
1954	23600	65200
1958	26900	54000
1960	15500	65200
1961	13000	74400
1962	12200	65200
1964	12800	142000
1965	20000	120000
1966	15300	80600
1967	8950	97900
1968	12500	112000
1971	9820	79100
1975	22600	122000
1979	22400	94500
1983	16400	66000
1985	15900	58900
1988	5870	24700
1993	19900	65200

N_1 = 30 years

N_2 = 28 years

$\overline{X}_1$ = 4.183551 log units

$\overline{X}_2$ = 4.175538 log units

S_{y1} = 0.2227034 log units

S_{x1} = 0.1851064 log units

$\overline{Y}_1$ = 4.906071 log units

r = 0.455 (correlation coefficient)

These values are substituted in Equation 7-5a of Bulletin 17B to get an improved estimate of the mean,

$\overline{Y} = 4.90395 \log$ units
$Sx_2 = 0.2040726 \log$ units (standard deviation of logarithms of Tar River peak flows for 1897-1929)

The above values are substituted in Equation 7-10 of Bulletin 17B to get improved estimates of the standard deviation, $Sy = 0.22425 \log$ units.

$\overline{X} = 4.179683 \log$ units
$S_x = 0.192811 \log$ units

The above values are substituted in the following equation to get the MOVE.2 relation

$$Y_{1695} = \overline{Y} + \frac{Sy}{Sx}\left[X_{1615} - \overline{X}\right]$$

$Y_{1695} = 4.90395 + 0.22425/0.192811 * [X_{1615} - 4.179683]$

Taking the antilog of the above equation yields Equation 6 given earlier in the text:

$Q_{1695} = 1.1034 * Q_{1615}{}^{1.16306}$.

Appendix 2. Flood frequency analysis for the period 1926 to 1998 – peak flows for 1926 to 1929 estimated by MOVE.2.

```
                    U. S. GEOLOGICAL SURVEY
                ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                 Following Bulletin 17-B Guidelines
                          Program peakfq
                     (Version 2.4, Apr, 1998)

     Station - 02169500                  CONGAREE RIVER AT COLUMBIA, SC
                        1900 MAY 24 15:20:59


               I N P U T   D A T A   S U M M A R Y

          Number of peaks in record        =         73
          Peaks not used in analysis       =          0
          Systematic peaks in analysis     =         73
          Historic peaks in analysis       =          0
          Years of historic record         =          0
          Generalized skew                 =      -0.100
          Standard error of generalized skew =    0.550
          Skew option                      = STATION SKEW
          Gage base discharge              =        0.0
          User supplied high outlier threshold =   --
          User supplied low outlier criterion  =   --
          Plotting position parameter      =       0.00


  *********  NOTICE  --  Preliminary machine computations.      *********
  *********  User responsible for assessment and interpretation. *********

   WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                 0.0
   WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.   310316.3
   WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.        17101.3
  *WCF151I-WRC WEIGHTED SKEW REPLACED BY USER OPTION.      0.328     0.471


     Station - 02169500                  CONGAREE RIVER AT COLUMBIA, SC
                        1900 MAY 24 15:20:59


          ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III
```

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	4.8624	0.2164	0.471
BULL.17B ESTIMATE	0.0	1.0000	4.8624	0.2164	0.471

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	84-PCT CONFIDENCE LIMITS FOR BULL. 17B LOWER	UPPER
0.9950	25130.0	25130.0	24470.0	22440.0	27740.0
0.9900	27200.0	27200.0	26600.0	24430.0	29880.0
0.9500	34480.0	34480.0	34060.0	31500.0	37360.0
0.9000	39650.0	39650.0	39330.0	36550.0	42650.0
0.8000	47550.0	47550.0	47340.0	44280.0	50750.0
0.5000	70060.0	70060.0	70060.0	66080.0	74250.0
0.2000	109100.0	109100.0	109800.0	102300.0	117000.0
0.1000	140700.0	140700.0	142600.0	130500.0	153200.0
0.0400	187900.0	187900.0	192600.0	171500.0	208700.0
0.0200	228800.0	228800.0	237100.0	206200.0	257900.0
0.0100	274900.0	274900.0	288700.0	244800.0	314500.0
0.0050	327200.0	327200.0	348800.0	287900.0	379600.0
0.0020	406900.0	406900.0	443800.0	352700.0	480700.0

       Station - 02169500   CONGAREE RIVER AT COLUMBIA, SC
                          1900 MAY 24 15:20:59

              I N P U T   D A T A   L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1926	45200.0		1963	91800.0	K
1927	30700.0		1964	142000.0	K
1928	300000.0		1965	120000.0	K
1929	157000.0		1966	80600.0	K
1930	303000.0		1967	97900.0	K
1931	26800.0	K	1968	61200.0	K
1932	71600.0	K	1969	94200.0	K
1933	115000.0	K	1970	45200.0	K
1934	33400.0	K	1971	79100.0	K
1935	92300.0	K	1972	63900.0	K
1936	231000.0	K	1973	99800.0	K
1937	70900.0	K	1974	51600.0	K
1938	57900.0	K	1975	122000.0	K
1939	66400.0	K	1976	48400.0	K
1940	121000.0	K	1977	155000.0	K
1941	52000.0	K	1978	81700.0	K
1942	52400.0	K	1979	94500.0	K
1943	63400.0	K	1980	93100.0	K
1944	105000.0	K	1981	51300.0	K
1945	102000.0	K	1982	84200.0	K
1946	62200.0	K	1983	66000.0	K

```
1947        63400.0      K      1984        70300.0      K
1948        54400.0      K      1985        54700.0      K
1949       116000.0      K      1986        58900.0      K
1950        50200.0      K      1987       123000.0      K
1951        32000.0      K      1988        24700.0      K
1952        91400.0      K      1989        48400.0      K
1953        43500.0      K      1990        93700.0      K
1954        65200.0      K      1991       135000.0      K
1955        47000.0      K      1992        51200.0      K
1956        43100.0      K      1993        65200.0      K
1957        31000.0      K      1994        72300.0      K
1958        64000.0      K      1995       116000.0      K
1959        53900.0      K      1996        74900.0      K
1960        65200.0      K      1997        50800.0      K
1961        74400.0      K      1998        95200.0      K
1962        65200.0      K
```

        Explanation of peak discharge qualification codes

     PEAKFQ   WATSTORE
      CODE   CODE   DEFINITION

        D   3   Dam failure, non-recurrent flow anomaly
        G   8   Discharge greater than stated value
        X   3+8   Both of the above
        L   4   Discharge less than stated value
        K   6 OR C   Known effect of regulation or urbanization
        H   7   Historic peak

Station - 02169500   CONGAREE RIVER AT COLUMBIA, SC
                              1900 MAY 24 15:20:59

  EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1930	303000.0	0.0135	0.0135
1928	300000.0	0.0270	0.0270
1936	231000.0	0.0405	0.0405
1929	157000.0	0.0541	0.0541
1977	155000.0	0.0676	0.0676
1964	142000.0	0.0811	0.0811
1991	135000.0	0.0946	0.0946
1987	123000.0	0.1081	0.1081
1975	122000.0	0.1216	0.1216
1940	121000.0	0.1351	0.1351
1965	120000.0	0.1486	0.1486
1949	116000.0	0.1622	0.1622
1995	116000.0	0.1757	0.1757
1933	115000.0	0.1892	0.1892
1944	105000.0	0.2027	0.2027
1945	102000.0	0.2162	0.2162

```
1973          99800.0          0.2297          0.2297
1967          97900.0          0.2432          0.2432
1998          95200.0          0.2568          0.2568
1979          94500.0          0.2703          0.2703
1969          94200.0          0.2838          0.2838
1990          93700.0          0.2973          0.2973
1980          93100.0          0.3108          0.3108
1935          92300.0          0.3243          0.3243
1963          91800.0          0.3378          0.3378
1952          91400.0          0.3514          0.3514
1982          84200.0          0.3649          0.3649
1978          81700.0          0.3784          0.3784
1966          80600.0          0.3919          0.3919
```

Appendix 3. Flood frequency analysis for the Congaree River for the period 1892 to 1998. Peaks flows prior to 1930 estimated with MOVE.2

```
                          U. S. GEOLOGICAL SURVEY
                      ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                       Following Bulletin 17-B Guidelines
                               Program peakfq
                            (Version 2.4, Apr, 1998)


         Station - 02169500          CONGAREE RIVER AT COLUMBIA, SC
                          1900 MAY 21 09:22:07


                   I N P U T   D A T A   S U M M A R Y

               Number of peaks in record           =        108
               Peaks not used in analysis          =          1
               Systematic peaks in analysis        =        107
               Historic peaks in analysis          =          0
               Years of historic record            =        146
               Generalized skew                    =      -0.100
               Standard error of generalized skew  =       0.550
               Skew option                         = STATION SKEW
               Gage base discharge                 =        0.0
               User supplied high outlier threshold =   299000.0
               User supplied low outlier criterion =       --
               Plotting position parameter         =       0.00


   *********  NOTICE  --  Preliminary machine computations.    *********
   *********  User responsible for assessment and interpretation.  *********


  **WCF109W-PEAKS WITH MINUS-FLAGGED DISCHARGES WERE BYPASSED.      1
  **WCF113W-NUMBER OF SYSTEMATIC PEAKS HAS BEEN REDUCED TO NSYS =  107
    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                 0.0
   *WCF161I-USER HIGH OUTLIER CRITERION REPLACES WRC.   299000.0   391284.4
    WCF165I-HIGH OUTLIERS AND HISTORIC PEAKS ABOVE HHBASE.  3  0   299000.1
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.        14353.0
   *WCF151I-WRC WEIGHTED SKEW REPLACED BY USER OPTION.     0.289     0.355  -
1
    WCF002J-CALCS COMPLETED.  RETURN CODE =  2



       Station - 02169500                 CONGAREE RIVER AT COLUMBIA, SC
                          1900 MAY 21 09:22:07


          ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III
```

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	4.8798	0.2346	0.419
BULL.17B ESTIMATE	0.0	1.0000	4.8750	0.2286	0.355

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	84-PCT CONFIDENCE LIMITS FOR BULL. 17B LOWER	UPPER
0.9950	23040.0	23320.0	22540.0	20820.0	25210.0
0.9900	25320.0	25540.0	24870.0	23020.0	27570.0
0.9500	33380.0	33410.0	33060.0	30850.0	35850.0
0.9000	39100.0	39060.0	38850.0	36430.0	41710.0
0.8000	47840.0	47770.0	47690.0	44990.0	50660.0
0.5000	72700.0	73030.0	72700.0	69090.0	76470.0
0.2000	115500.0	117800.0	115900.0	109100.0	122700.0
0.1000	149700.0	154500.0	151100.0	140100.0	161000.0
0.0400	200300.0	210000.0	203700.0	185000.0	219000.0
0.0200	243700.0	258500.0	249600.0	222700.0	269500.0
0.0100	292100.0	313600.0	301800.0	264400.0	326900.0
0.0050	346400.0	376400.0	361400.0	310500.0	392100.0
0.0020	428400.0	472800.0	453400.0	379300.0	491800.0

Station - 02169500   CONGAREE RIVER AT COLUMBIA, SC
                        1900 MAY 21 09:22:07

I N P U T   D A T A   L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1852	-8888.0		1945	102000.0	K
1892	139000.0		1946	62200.0	K
1893	95700.0		1947	63400.0	K
1894	40000.0		1948	54400.0	K
1895	89000.0		1949	116000.0	K
1896	67000.0		1950	50200.0	K
1897	100000.0		1951	32000.0	K
1898	30700.0		1952	91400.0	K
1899	102000.0		1953	43500.0	K
1900	105000.0		1954	65200.0	K
1901	117000.0		1955	47000.0	K
1902	105000.0		1956	43100.0	K
1903	179000.0		1957	31000.0	K
1904	38000.0		1958	64000.0	K
1905	48600.0		1959	53900.0	K
1906	88100.0		1960	65200.0	K
1907	26700.0		1961	74400.0	K
1908	357000.0		1962	65200.0	K
1909	105000.0		1963	91800.0	K
1910	44600.0		1964	142000.0	K
1911	33100.0		1965	120000.0	K

```
     1912       242000.0                    1966        80600.0      K
     1913       120000.0                    1967        97900.0      K
     1914        48200.0                    1968        61200.0      K
     1915        64200.0                    1969        94200.0      K
     1916       259000.0                    1970        45200.0      K
     1917        67000.0                    1971        79100.0      K
     1918        38000.0                    1972        63900.0      K
     1919        91900.0                    1973        99800.0      K
     1920        80600.0                    1974        51600.0      K
     1921       134000.0                    1975       122000.0      K
     1922       108000.0                    1976        48400.0      K
     1923        66300.0                    1977       155000.0      K
     1924        53300.0                    1978        81700.0      K
     1925       124000.0                    1979        94500.0      K
     1926        45200.0                    1980        93100.0      K
     1927        30700.0                    1981        51300.0      K
     1928       300000.0                    1982        84200.0      K
     1929       157000.0                    1983        66000.0      K
     1930       303000.0                    1984        70300.0      K
     1931        26800.0     K              1985        54700.0      K
     1932        71600.0     K              1986        58900.0      K
     1933       115000.0     K              1987       123000.0      K
     1934        33400.0     K              1988        24700.0      K
     1935        92300.0     K              1989        48400.0      K
     1936       231000.0     K              1990        93700.0      K
     1937        70900.0     K              1991       135000.0      K
     1938        57900.0     K              1992        51200.0      K
     1939        66400.0     K              1993        65200.0      K
     1940       121000.0     K              1994        72300.0      K
     1941        52000.0     K              1995       116000.0      K
     1942        52400.0     K              1996        74900.0      K
     1943        63400.0     K              1997        50800.0      K
     1944       105000.0     K              1998        95200.0      K
     Explanation of peak discharge qualification codes
```

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

```
Station - 02169500                     CONGAREE RIVER AT COLUMBIA, SC
                          1900 MAY 21 09:22:07


   EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS
```

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1908	357000.0	0.0093	0.0068
1930	303000.0	0.0185	0.0136
1928	300000.0	0.0278	0.0204

1916	259000.0	0.0370	0.0285
1912	242000.0	0.0463	0.0378
1936	231000.0	0.0556	0.0472
1903	179000.0	0.0648	0.0565
1929	157000.0	0.0741	0.0659
1977	155000.0	0.0833	0.0753
1964	142000.0	0.0926	0.0846
1892	139000.0	0.1019	0.0940
1991	135000.0	0.1111	0.1033
1921	134000.0	0.1204	0.1127
1925	124000.0	0.1296	0.1220
1987	123000.0	0.1389	0.1314
1975	122000.0	0.1481	0.1407
1940	121000.0	0.1574	0.1501
1913	120000.0	0.1667	0.1594
1965	120000.0	0.1759	0.1688
1901	117000.0	0.1852	0.1781
1949	116000.0	0.1944	0.1875
1995	116000.0	0.2037	0.1969
1933	115000.0	0.2130	0.2062
1922	108000.0	0.2222	0.2156
1900	105000.0	0.2315	0.2249
1902	105000.0	0.2407	0.2343
1909	105000.0	0.2500	0.2436
1944	105000.0	0.2593	0.2530
1899	102000.0	0.2685	0.2623
1945	102000.0	0.2778	0.2717
1897	100000.0	0.2870	0.2810
1973	99800.0	0.2963	0.2904
1967	97900.0	0.3056	0.2997
1893	95700.0	0.3148	0.3091
1998	95200.0	0.3241	0.3185
1979	94500.0	0.3333	0.3278
1969	94200.0	0.3426	0.3372
1990	93700.0	0.3519	0.3465
1980	93100.0	0.3611	0.3559
1935	92300.0	0.3704	0.3652
1919	91900.0	0.3796	0.3746
1963	91800.0	0.3889	0.3839
1952	91400.0	0.3981	0.3933
1895	89000.0	0.4074	0.4026
1906	88100.0	0.4167	0.4120
1982	84200.0	0.4259	0.4213
1978	81700.0	0.4352	0.4307
1920	80600.0	0.4444	0.4401
1966	80600.0	0.4537	0.4494
1971	79100.0	0.4630	0.4588
1996	74900.0	0.4722	0.4681
1961	74400.0	0.4815	0.4775
1994	72300.0	0.4907	0.4868
1932	71600.0	0.5000	0.4962
1937	70900.0	0.5093	0.5055
1984	70300.0	0.5185	0.5149
1896	67000.0	0.5278	0.5242
1917	67000.0	0.5370	0.5336

1939	66400.0	0.5463	0.5429
1923	66300.0	0.5556	0.5523
1983	66000.0	0.5648	0.5616
1954	65200.0	0.5741	0.5710
1960	65200.0	0.5833	0.5804
1962	65200.0	0.5926	0.5897
1993	65200.0	0.6019	0.5991
1915	64200.0	0.6111	0.6084
1958	64000.0	0.6204	0.6178
1972	63900.0	0.6296	0.6271
1943	63400.0	0.6389	0.6365
1947	63400.0	0.6481	0.6458
1946	62200.0	0.6574	0.6552
1968	61200.0	0.6667	0.6645
1986	58900.0	0.6759	0.6739
1938	57900.0	0.6852	0.6832
1985	54700.0	0.6944	0.6926
1948	54400.0	0.7037	0.7020
1959	53900.0	0.7130	0.7113
1924	53300.0	0.7222	0.7207
1942	52400.0	0.7315	0.7300
1941	52000.0	0.7407	0.7394
1974	51600.0	0.7500	0.7487
1981	51300.0	0.7593	0.7581
1992	51200.0	0.7685	0.7674
1997	50800.0	0.7778	0.7768
1950	50200.0	0.7870	0.7861
1905	48600.0	0.7963	0.7955
1976	48400.0	0.8056	0.8048
1989	48400.0	0.8148	0.8142
1914	48200.0	0.8241	0.8236
1955	47000.0	0.8333	0.8329
1926	45200.0	0.8426	0.8423
1970	45200.0	0.8519	0.8516
1910	44600.0	0.8611	0.8610
1953	43500.0	0.8704	0.8703
1956	43100.0	0.8796	0.8797
1894	40000.0	0.8889	0.8890
1904	38000.0	0.8981	0.8984
1918	38000.0	0.9074	0.9077
1934	33400.0	0.9167	0.9171
1911	33100.0	0.9259	0.9264
1951	32000.0	0.9352	0.9358
1957	31000.0	0.9444	0.9452
1898	30700.0	0.9537	0.9545
1927	30700.0	0.9630	0.9639
1931	26800.0	0.9722	0.9732
1907	26700.0	0.9815	0.9826
1988	24700.0	0.9907	0.9919
1852	-8888.0	--	--

Appendix 4. Flood frequency analyses for the Congaree River using extended record based on a MOVE.2 analysis with the Tar River at Tarboro, North Carolina.

```
                      U. S. GEOLOGICAL SURVEY
                 ANNUAL PEAK FLOW FREQUENCY ANALYSIS
                   Following Bulletin 17-B Guidelines
                         Program peakfq
                      (Version 2.4, Apr, 1998)


      Station - 02169500          CONGAREE RIVER AT COLUMBIA, SC
                      1900 JUL 11 14:10:37



              I N P U T   D A T A   S U M M A R Y

            Number of peaks in record          =       97
            Peaks not used in analysis         =        0
            Systematic peaks in analysis       =       97
            Historic peaks in analysis         =        0
            Years of historic record           =        0
            Generalized skew                   =    -0.100
            Standard error of generalized skew =     0.550
            Skew option                        = STATION SKEW
            Gage base discharge                =      0.0
            User supplied high outlier threshold =    --
            User supplied low outlier criterion  =    --
            Plotting position parameter        =      0.00


  *********  NOTICE  --  Preliminary machine computations.      *********
  *********  User responsible for assessment and interpretation.  *********

   WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.             0.0
   WCF162I-SYSTEMATIC PEAKS EXCEEDED HIGH-OUTLIER CRITERION.   1 317711.0
   WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.        17232.4
  *WCF151I-WRC WEIGHTED SKEW REPLACED BY USER OPTION.    0.471    0.643
-1


      Station - 02169500                CONGAREE RIVER AT COLUMBIA, SC
                      1900 JUL 11 14:10:37



          ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


                    FLOOD BASE                    LOGARITHMIC
               ---------------------   -------------------------------
                          EXCEEDANCE              STANDARD
               DISCHARGE PROBABILITY    MEAN      DEVIATION    SKEW
               ----------------------------------------------------------
SYSTEMATIC RECORD     0.0     1.0000    4.8692      0.2105     0.643
BULL.17B ESTIMATE     0.0     1.0000    4.8692      0.2105     0.643
```

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	84-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES	
				LOWER	UPPER
0.9950	28370.0	28370.0	27940.0	25930.0	30730.0
0.9900	30200.0	30200.0	29810.0	27720.0	32600.0
0.9500	36760.0	36760.0	36470.0	34140.0	39300.0
0.9000	41490.0	41490.0	41270.0	38790.0	44120.0
0.8000	48830.0	48830.0	48690.0	46010.0	51610.0
0.5000	70270.0	70270.0	70270.0	66880.0	73800.0
0.2000	108800.0	108800.0	109300.0	103000.0	115400.0
0.1000	141000.0	141000.0	142500.0	132200.0	151400.0
0.0400	190500.0	190500.0	194300.0	176000.0	208200.0
0.0200	234500.0	234500.0	241300.0	214200.0	259900.0
0.0100	285400.0	285400.0	296800.0	257700.0	320500.0
0.0050	344200.0	344200.0	362600.0	307300.0	391700.0
0.0020	436300.0	436300.0	468400.0	383900.0	505000.0

Station - 02169500   CONGAREE RIVER AT COLUMBIA, SC
                         1900 JUL 11 14:10:37

                  I N P U T   D A T A   L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1897	76900.0		1951	32000.0	K
1898	42100.0		1952	91400.0	K
1899	127000.0		1953	43500.0	K
1900	67000.0		1954	65200.0	K
1906	89300.0		1955	47000.0	K
1907	69600.0		1956	43100.0	K
1908	159000.0		1957	31000.0	K
1909	58300.0		1958	64000.0	K
1910	131000.0		1959	53900.0	K
1911	45000.0		1960	65200.0	K
1912	46600.0		1961	74400.0	K
1913	69600.0		1962	65200.0	K
1914	55000.0		1963	91800.0	K
1915	54800.0		1964	142000.0	K
1916	42500.0		1965	120000.0	K
1917	86800.0		1966	80600.0	K
1918	67800.0		1967	97900.0	K
1919	343000.0		1968	61200.0	K
1920	54800.0		1969	94200.0	K
1921	44000.0		1970	45200.0	K
1922	120000.0		1971	79100.0	K
1923	82500.0		1972	63900.0	K

```
1924     65400.0              1973     99800.0    K
1925    247000.0              1974     51600.0    K
1926     55000.0              1975    122000.0    K
1927     47000.0              1976     48400.0    K
1928    172000.0              1977    155000.0    K
1929    110000.0              1978     81700.0    K
1930    303000.0              1979     94500.0    K
1931     26800.0    K         1980     93100.0    K
1932     71600.0    K         1981     51300.0    K
1933    115000.0    K         1982     84200.0    K
1934     33400.0    K         1983     66000.0    K
1935     92300.0    K         1984     70300.0    K
1936    231000.0    K         1985     54700.0    K
1937     70900.0    K         1986     58900.0    K
1938     57900.0    K         1987    123000.0    K
1939     66400.0    K         1988     24700.0    K
1940    121000.0    K         1989     48400.0    K
1941     52000.0    K         1990     93700.0    K
1942     52400.0    K         1991    135000.0    K
1943     63400.0    K         1992     51200.0    K
1944    105000.0    K         1993     65200.0    K
1945    102000.0    K         1994     72300.0    K
1946     62200.0    K         1995    116000.0    K
1947     63400.0    K         1996     74900.0    K
1948     54400.0    K         1997     50800.0    K
1949    116000.0    K         1998     95200.0    K
1950     50200.0    K
```

```
    Explanation of peak discharge qualification codes

    PEAKFQ   WATSTORE
     CODE     CODE    DEFINITION


      D        3      Dam failure, non-recurrent flow anomaly
      G        8      Discharge greater than stated value
      X       3+8     Both of the above
      L        4      Discharge less than stated value
      K     6 OR C    Known effect of regulation or urbanization
      H        7      Historic peak
```

```
   Station - 02169500                  CONGAREE RIVER AT COLUMBIA, SC
                       1900 JUL 11 14:10:37
```

```
  EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

   WATER        RANKED      SYSTEMATIC     BULL.17B
    YEAR      DISCHARGE       RECORD       ESTIMATE


    1919      343000.0        0.0102        0.0102
    1930      303000.0        0.0204        0.0204
    1925      247000.0        0.0306        0.0306
    1936      231000.0        0.0408        0.0408
```

1928	172000.0	0.0510	0.0510
1908	159000.0	0.0612	0.0612
1977	155000.0	0.0714	0.0714
1964	142000.0	0.0816	0.0816
1991	135000.0	0.0918	0.0918
1910	131000.0	0.1020	0.1020
1899	127000.0	0.1122	0.1122
1987	123000.0	0.1224	0.1224
1975	122000.0	0.1327	0.1327
1940	121000.0	0.1429	0.1429
1922	120000.0	0.1531	0.1531
1965	120000.0	0.1633	0.1633
1949	116000.0	0.1735	0.1735
1995	116000.0	0.1837	0.1837
1933	115000.0	0.1939	0.1939
1929	110000.0	0.2041	0.2041
1944	105000.0	0.2143	0.2143
1945	102000.0	0.2245	0.2245
1973	99800.0	0.2347	0.2347
1967	97900.0	0.2449	0.2449
1998	95200.0	0.2551	0.2551
1979	94500.0	0.2653	0.2653
1969	94200.0	0.2755	0.2755
1990	93700.0	0.2857	0.2857
1980	93100.0	0.2959	0.2959
1935	92300.0	0.3061	0.3061
1963	91800.0	0.3163	0.3163
1952	91400.0	0.3265	0.3265
1906	89300.0	0.3367	0.3367
1917	86800.0	0.3469	0.3469
1982	84200.0	0.3571	0.3571
1923	82500.0	0.3673	0.3673
1978	81700.0	0.3776	0.3776
1966	80600.0	0.3878	0.3878
1971	79100.0	0.3980	0.3980
1897	76900.0	0.4082	0.4082
1996	74900.0	0.4184	0.4184
1961	74400.0	0.4286	0.4286
1994	72300.0	0.4388	0.4388
1932	71600.0	0.4490	0.4490
1937	70900.0	0.4592	0.4592
1984	70300.0	0.4694	0.4694
1907	69600.0	0.4796	0.4796
1913	69600.0	0.4898	0.4898
1918	67800.0	0.5000	0.5000
1900	67000.0	0.5102	0.5102
1939	66400.0	0.5204	0.5204
1983	66000.0	0.5306	0.5306
1924	65400.0	0.5408	0.5408
1954	65200.0	0.5510	0.5510
1960	65200.0	0.5612	0.5612
1962	65200.0	0.5714	0.5714
1993	65200.0	0.5816	0.5816
1958	64000.0	0.5918	0.5918
1972	63900.0	0.6020	0.6020

1943	63400.0	0.6122	0.6122
1947	63400.0	0.6224	0.6224
1946	62200.0	0.6327	0.6327
1968	61200.0	0.6429	0.6429
1986	58900.0	0.6531	0.6531
1909	58300.0	0.6633	0.6633
1938	57900.0	0.6735	0.6735
1914	55000.0	0.6837	0.6837
1926	55000.0	0.6939	0.6939
1915	54800.0	0.7041	0.7041
1920	54800.0	0.7143	0.7143
1985	54700.0	0.7245	0.7245
1948	54400.0	0.7347	0.7347
1959	53900.0	0.7449	0.7449
1942	52400.0	0.7551	0.7551
1941	52000.0	0.7653	0.7653
1974	51600.0	0.7755	0.7755
1981	51300.0	0.7857	0.7857
1992	51200.0	0.7959	0.7959
1997	50800.0	0.8061	0.8061
1950	50200.0	0.8163	0.8163
1976	48400.0	0.8265	0.8265
1989	48400.0	0.8367	0.8367
1927	47000.0	0.8469	0.8469
1955	47000.0	0.8571	0.8571
1912	46600.0	0.8673	0.8673
1970	45200.0	0.8776	0.8776
1911	45000.0	0.8878	0.8878
1921	44000.0	0.8980	0.8980
1953	43500.0	0.9082	0.9082
1956	43100.0	0.9184	0.9184
1916	42500.0	0.9286	0.9286
1898	42100.0	0.9388	0.9388
1934	33400.0	0.9490	0.9490
1951	32000.0	0.9592	0.9592
1957	31000.0	0.9694	0.9694
1931	26800.0	0.9796	0.9796
1988	24700.0	0.9898	0.9898